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ORIGINAL COMMUNICATIONS.

FORM, ENDINGS AND RELATIONS OF STRIATED, MUSCULAR FIBERS IN THE MUSCLES OF MINUTE ANIMALS (MOUSE, SHREW, BAT AND ENGLISH SPARROW.)*

[THREE PLATES.]

SUSANNA PHELPS GAGE, PH. B.

PART I.

IN Kölliker's †Histology, (1867) p. 158, occurs the following statement: "In short muscles (the side muscles of fish, the limb muscles of the bat and the muscles of the frog) all the fibers are of the length of the muscle and have rounded ends. In long muscles the fibers are from 30 to 40 mm. in length. Far more numerous investigations are necessary to determine whether in all muscles of less length than 30 to 40 mm., the fibers are as long as the muscle itself." Since 1867 investigations as to the form and length of muscular fibers have not been numerous and, as far as I know, have been turned exclusively in the direction of man and the larger animals.

In order to carry the knowledge of the more obvious structure of muscle a step farther it was thought desirable to determine the length, form and relation of the fibers in minute animals. The larger part of the present investigation was made upon mice.

*The work on this article was done in the Anatomical Laboratory of Cornell University, and its main features were presented at the meeting of the American Society of Microscopists, August, 1887.

†For all references to authors see the alphabetically arranged bibliography at the end of Part II, where will be found briefly summarized the literature bearing directly upon this paper.

Several English sparrows were also studied, while only one shrew and two bats were examined.* The longest muscle found in these animals, the *latissimus* of a field mouse, was 27 mm. long, which is less than 30 mm., the number mentioned by Kölliker and usually accepted as the lowest limit of a fiber in a long muscle from any of the larger animals.

In general form the fibers of the trunk and limb muscles of these small animals are of three kinds—cylindrical, tapering and fusiform. Their arrangement is diagrammatically shown in Plate I., Figs. 1 to 9.

1. CYLINDRICAL FIBERS—Are those which extend from tendon to tendon of the muscle with a nearly uniform diameter (Fig. 1). In the shorter muscles these were the only kind found.† This was found to be the case in the intercostals ($3\frac{1}{2}$ to 4 mm.), the short muscles of the back (5 mm.) and the diaphragm (4 mm.) of the mouse and bat; the penniform muscles from both cephalic and caudal limbs of the mouse, bat and sparrow (the fibers varying in different muscles and in different parts of the same muscle from 1 to 7 mm.), and in the *rectus abdominis* of the mouse, a polygastric muscle, the sections between the raphes being 4 to 5 mm.

One of the longer muscles (10 mm.) from the shoulder of a mouse seemed also to be composed entirely of fibers which extend from tendon to tendon, while in the *latissimus* (25 to 27 mm.) of the mouse no fibers were traced the full length of the muscle. In some of the longer muscles the majority of the fibers extend from tendon to tendon, as in the *rectus capitis* (9 mm.) of the mouse. In others only occasionally could a fiber be traced from one end of the muscle to the other. This was done in the *vastus externus* of the mouse, a muscle varying in different specimens from 16 to 22 mm., and in the same muscle (9 mm.) of the bat, the shrew (8 mm.) and the English sparrow (14 mm.); in the pectoral (18 mm.), the *trapezius* (15 mm.) and the *obliquus abdominis* (14 mm.) of the mouse; in the rhomboid of the English sparrow and the *obliquus abdominis* of the bat. While there seem to be few cylindrical fibers in these longer muscles, their apparent rarity may be partially due to the difficulty of isolating them sufficiently to trace them.

2. TAPERING FIBERS—Are those having one termination large and more or less blunt at one tendinous attachment of the muscle,

* The species studied were the house mouse (*Mus musculus* [Linn]), both young and adult, the field mouse (*Hesperomys leucopus* [Raf.]), adult, the mole shrew (*Blarina brevicauda* [Say]), the brown bat (*Vespertilio subulatus* [Say]), the gray bat (*Atalapha cinereus* [Beauv.]), and the English sparrow (*Passer domesticus* [Linn]), both young and adult.

† For convenience the muscles may be classified as shorter, those 7 mm. and less between the tendons, and longer, those 8 mm. and over.

the other and tapering termination not extending to the other tendon but ending within the muscle. I shall call the two terminations respectively, the *tendinous* and the *intramuscular* end of the fiber. Figs. 2, 8 and 13 show the relative diameter of these fibers in their different parts, the middle section in each (*b*), the body of the fiber, should be greatly elongated, 40 to 100 times, in order to give an adequate idea of the real form of the fiber. Fibers of this kind were isolated in the *latissimus*, *trapezius*, *pectoralis*, *vastus externus*, *rhomboideus*, *obliquus abdominis* and *rectus capitis* of the mouse, in the *rectus capitis*, *rhomboideus*, *vastus externus* and two muscles of the brachium of the English sparrow, that is in both limb and trunk muscles. Intramuscular ends were also found where the fibers were not traced their entire length. Most such ends probably belong to tapering fibers. They are found in muscles varying in length from 5 to 27 mm. as the *latissimus*, *trapezius* and *pectoralis* of the English sparrow, the *latissimus*, *pectoralis*, *trapezius*, *vastus externus*, *obliquus abdominis* and one from the back of the bat, and the *latissimus*, *pectoralis* and *vastus externus* of the shrew.

In general it may be said that the longer the muscle, the more tapering fibers and intramuscular ends were found. There was no observable difference in number on account of the muscles belonging to the trunk or the limbs, nor on account of the species, as in the mouse and bat, nor the age of the animal as in the mouse and sparrow, nor the method of dissociation, whether by nitric acid or caustic potash, provided the specimen was quite fresh.

3. FUSIFORM FIBERS.—Are those which taper at both ends (Fig. 9). It seems probable that both ends are intramuscular as is so common in the larger animals. In the skeletal muscles only a few fibers of this type were found and these were from the mouse. There were two, each about 10 mm. long from the *latissimus*, a muscle 25 mm. long, one from the *obliquus abdominis*, one 2 mm. long from the *vastus externus*, a muscle 16 mm. long, and two others, each 7 mm. long, from the same muscle. The ends in the last named case are clearly intramuscular. In all of these cases the diameter of the fiber is small, that is about one-half the average size.

4. LENGTH OF TAPERING FIBERS.*—The length of the isolated fibers mentioned under 2, vary in the sparrow from 4 mm. in one muscle (8 mm. long) from the brachium, to 10 mm. in another muscle (18 mm. long) from the brachium; and in the mouse from 6 mm. in the rhomboid (10 mm. long) to 14 mm. in the pectoral (18 mm. long). A

*The fibers, the length of which is here given, were dissociated *in situ* (see methods Part II), so that only slight allowance need be made for shrinkage.

frequent length of tapering fibers in both animals is 6 to 9 mm. and generally speaking, they are from one-half to two-thirds the length of the muscle in which they occur, but occasionally, as in the rhomboid, which is 9 mm. long, and the *rectus capitis*, which is 5 mm. long, they extend from one tendon nearly to the other.

Owing to the difficulty of preparation, perfectly isolated tapering fibers are comparatively few, hence it seems desirable to confirm the above statement by other facts. (*a.*) Intramuscular ends of fibers which were not traced to the other end, are generally found near the middle and in the middle third of the muscle and only occasionally near the tendon. Of the last, some perhaps may belong to fusiform fibers (see 3). (*b.*) In dissecting thoroughly dissociated muscles by needles, an apparent rupture sometimes occurred at about the middle of the muscle. This proved, upon examination, not to be a tear, but on each side of the break were found groups of tapering intramuscular ends which evidently had interdigitated, and which belong to fibers, somewhat over half the length of the muscle, coming from opposite tendons. (*c.*) The examination of serial transections of the *vastus externus* of the mouse shows that while occasionally not far from a tendon is a fiber of very small diameter, that is the tapering end of fiber, the majority of such ends is near the middle of the muscle (Figs. 19–21).

From all these facts it seems justifiable to say that tapering fibers in these animals are generally from one-half to two-thirds of the length of the muscle in which they occur, that is from 3 to 18 or 20 mm. long, with an occasional one which is nearly as long as the muscle itself.

5. DIAMETER OF FIBERS.—Fibers from the mouse show in transection a great variety of form, being circular, triangular, quadrilateral, etc. (Fig. 19–22). Isolated fibers from all the small animals examined gave evidence of a similar variety in form, some of them when twisted show that they are even ribbon-shaped. The intramuscular ends approach more nearly to the cylindrical form than the fibers at their full size, as seen in section (compare Fig. 20 and 22), but even here they are often irregular (Fig. 21). In isolated preparations the simple tapering form of intramuscular end (Fig. 2–4) gives the appearance of a more regular cylindrical form than a branched ending does, as shown when an end rolls over or is twisted, while the tendinous ends frequently appear thin and much expanded laterally (Fig. 6), or compressed and tapering (Fig. 5). From these facts it is seen that though the type of the fiber is either cyl-

indrical or tapering, the deviation from the type is in all directions and at all parts of the fiber. These statements are based upon specimens subjected to reagents, as no determination of the form of the fiber was attempted on fresh material.

The measurement of the diameter of fibers offers serious difficulties. Apparently the most simple method would be to measure the sections of fibers, but this was abandoned owing to the inconstancy of the fascicules (see Part II.) and consequent difficulty in tracing the individual fibers through a series of sections in order to find where they are of full size. In isolated preparations, though it is not so difficult to determine what part of a fiber to measure, there are two sources of error. In the dissociating agents used, the fibers shrink in length, and consequently increase in diameter, and though the two diameters at a given point may be so different, as shown in sections (Fig. 20), only one of them can ordinarily be measured. The average diameter of twenty fibers from the *vastus externus* of the mouse, in the fresh state, was 50μ—the largest and smallest being 80μ and 30μ; the average of thirty fibers dissociated in caustic potash and showing a decided shrinkage in length was 53μ, the largest and smallest being 80μ and 30μ; the average of thirty fibers, dissociated in nitric acid *in situ*, and having a shrinkage of one-ninth their length, was 56μ, the largest and smallest being 100μ and 20μ; the average of thirty fibers dissociated in nitric acid, and having a shrinkage of one-third in length was 70μ, the largest and smallest being 100μ and 30μ. In the other animals studied, the average diameter of the fibers was considerably less.

Tendinous ends were found varying from 20μ to 125μ, and intramuscular ends from 2μ to 20μ, depending on the bluntness of the end and the part measured.

According to Rollett (1856) fibers which end within a muscle are small in diameter throughout their whole length. He assumed that they are developing fibers which do not yet reach from tendon to tendon. In the mouse and sparrow this is clearly not the case, as some fibers which extend from tendon to tendon are small and others large, while some tapering fibers with intramuscular ends are large (Fig. 12) and others small (Fig. 8). In the *trapezius* and the abdominal muscles of the mouse, fibers which extend side by side from tendon to tendon, show a great difference in size, one being three or four times as large as another (Fig. 6 and 8, and also Fig. 47, Pl. XII in Part II).

6. IN THE SKIN AND MUCOSA so clear a determination of the

general form and relations of the striated muscular fibers could not be made. In the skin the connective tissue does not yield to reagents until the fibers are too much softened to be dissected well, and in the tongue and œsophagus the fibers are interlaced in such a way as to make it difficult either to dissect them out or to trace them under the microscope in their natural relations. In the skin of the ear of the mouse, however, the circumstances are more favorable, and it was found that there are only cylindrical fibers which are very short $\frac{1}{2}$ to 2 or 3 mm. *In situ* these are seen to be arranged in small bundles and the bundles are placed at a variety of angles with each other. In the long skin muscle of the back no cylindrical fibers could be traced in either the bat or the mouse. A few tapering fibers and one fusiform fiber (6 mm.) were found in the mouse.

Of the large number of fine tapering ends found in the skin muscles of the back it was often impossible to determine whether they were intramuscular or terminated in the corium. A few were found *in situ* part of these being closely attached to other fibers and part ending in the corium.

In the tongue of the mouse and bat there are groups of parallel fibers, the terminations of which are at about the same level and apparently in the corium. Their relative position is shown in Figs. 28 to 30. The ends are usually wider than the body of the fiber (Fig. 28). A few short fibers, about 2 mm., were isolated from the tongue of the mouse, each of which had two such endings.

In the œsophagus of the mouse and bat two layers of striated fibers were found which extend to, but not upon, the stomach. In the centimeter next the stomach there were also numerous unstriated fibers. A few short, striated fibers, about 2 or 3 mm., were isolated. They taper somewhat toward the end but generally at the end again spread out (Fig. 24).

In these positions the fibers have a much smaller average diameter than in the limb and trunk muscles, being about one-half as large.

7. TYPES OF INTRAMUSCULAR ENDS.—Rollett (1856) first described and figured intramuscular ends of a simple tapering form. In all the animals considered in this paper, such ends were found in many of the skeletal muscles having tapering fibers (Figs. 2 and 4). They are found occasionally in the mouse and shrew, frequently in the bat and are the predominant form in the English sparrow.

Biesiadecki and Herzig (1858) showed that in the horse, frog and *Lota vulgaris* are found dichotomously divided ends within the

muscle and that, in the horse, from the side of some fibers extend "short hook-like appendages," compare Fig. 11. Branched endings have been figured also from the ocular muscles of the sheep (Tergast), the iris of birds (Dogiel) and some muscles of the cat (Gage).

In the mouse intramuscular ends in limb and trunk muscles are very numerous and have great variety in the form of the branching. The figures in Plate VIII and IX, though not all taken from the mouse, were found in prototype in that animal. The branches may be near the tip (Fig. 6), or arranged at intervals along the side of the fiber until it is of full size (Fig. 13), or the branches themselves may branch (Fig. 17). In the shrew many branched endings were found and the forms varied nearly as much as did those in the mouse. In the bat only two branched endings (Fig. 16) were found but the state of the specimens might account for this, as to demonstrate branched endings it seems necessary to have perfectly fresh material. In the sparrow branched endings are rare and the form of the branching shows less variety and is less marked (Figs. 10 and 11) than in the mouse or shrew.

A few endings both tapering and branched, which could strictly be called intramuscular, were found in the skin of the mouse (Fig. 7), while in the tongue one tapering and slightly branched end was found which was surely intramuscular.

The length of the taper before the fiber attains full size varies greatly, in some cases where the fiber breaks up suddenly into branches near the tip, being only 1 mm., in others extending 5 to 6 mm. It is usually, however, found to be 2 or 3 mm., and may be said to be from one-eighth to one-fifth of the length of a tapering fiber.

8. TYPES OF TENDINOUS ENDS.—The tendinous end of fibers, as usually figured, resembles the ends of Fig. 1 and 5, being either slightly compressed, pointed or truncate with short, finger-like divisions. In the small animals these forms are in the majority, but there are also found many endings of quite different forms. Fig. 4 shows a form in which the whole end (*t.*) has a great number of fine, short processes, with no striation, giving it a fringed appearance. This form was met with in the mouse, bat and sparrow, and in both nitric acid and caustic potash preparations. Figs. 6 and 32 show tendinous ends of various forms, being cleft or having both large and small branches. Some of the branches are given off as far as ½ mm. from the tendon. Forms of this description were found in limb muscles

of the mouse, bat and sparrow, and in the *obliquus abdominis* of the mouse.

An extreme case of division at the tendinous end was found in a short fiber, 4.5 mm. long, from a penniform muscle of the antebrachium of a mouse (Fig. 34). The division extends about 1.5 mm., one-third the length of the fiber.

For convenience, the large branched endings of fibers from the skin and mucosa will be classified with the tendinous ends. Their position at the end of the muscle, and their size in relation to the body of the fiber to which they belong, give them a much closer resemblance to the tendinous than to the intramuscular end of fibers from limb and trunk muscles. In form, their resemblance to tendinous ends can be seen by comparing Figs. 24, 31 and 33 with Figs. 6 and 32. Frequently, however, these ends become much expanded laterally (Figs. 27–30). They often have fine, hair-like and root-like branches or processes (Fig. 27), which may be compared to those of Fig. 4*t*, and Fig. 6*t*. These forms are similar to those figured by Busk and Huxley in the skin of the rat's lip, to those described by Kölliker, and figured by Biesiadecki and Herzig in the frog's tongue, and to those figured by Margo from the alimentary canal of invertebrates.

9. BRANCHING OF FIBERS AT FULL SIZE.—Besides the branching already mentioned, there occurs occasionally in the limb and trunk muscles of the mouse, bat and shrew, a more or less equal division of the fiber at its full size into two parts. This is of frequent occurrence in the fibers of the tongue and œsophagus of the mouse and bat (Fig. 26).

10. The fiber represented by Fig. 23 is a unique example, showing a fiber which appears to be splitting longitudinally. The clefts in the specimen have the clear outlines of a natural contour and do not at all resemble artificial tears. A noteworthy feature of this fiber is the longitudinal rows of nuclei, some of them dividing, which extend from the ends of the clefts. In works on development of muscle it is frequently asked if fibers multiply in number by longitudinal division. No valid conclusions could be drawn from one example.

SUMMARY.

From the above it will be seen that in small animals muscular fibers may extend from tendon to tendon, or one or both ends may terminate within the muscle. The difference in this respect between those and the larger animals is chiefly that in the latter there are many more spindle-shaped fibers with both ends intramuscular.

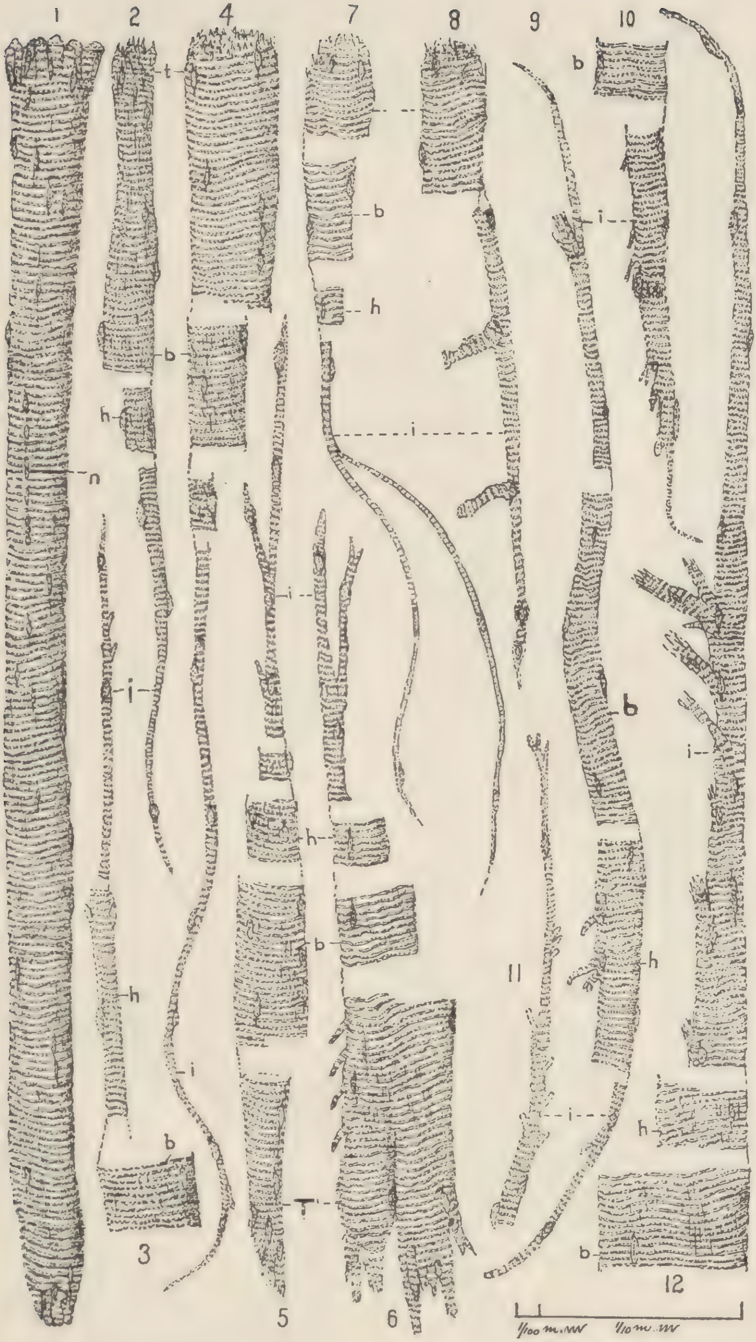

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PLATE VIII.

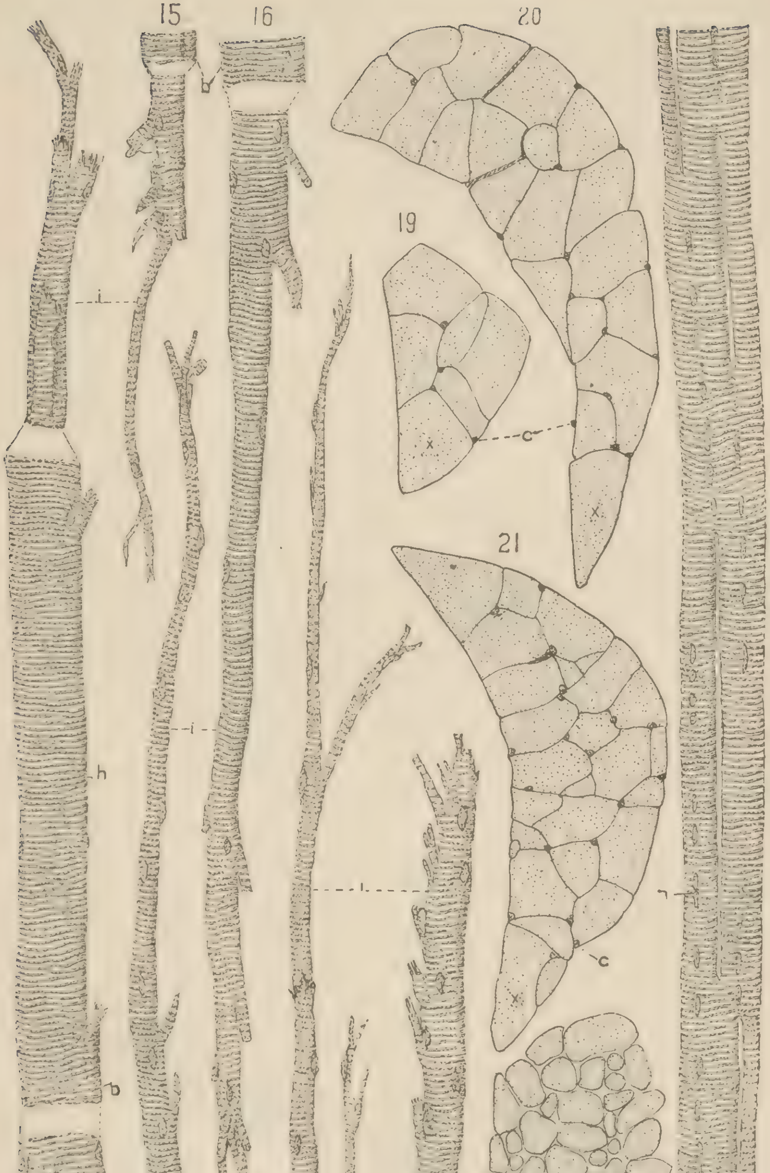

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PLATE IX.

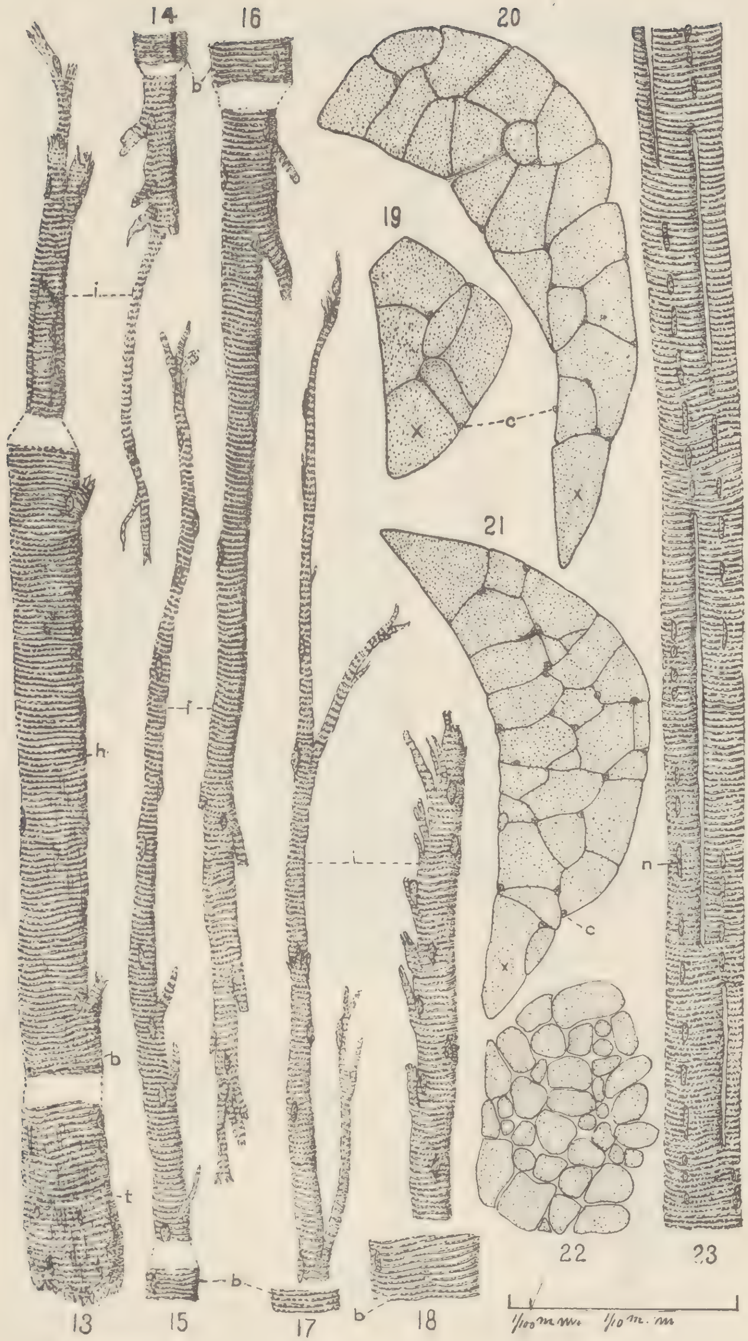

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PLATE IX.

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PLATE X.

Tapering fibers are generally one-half to two-thirds the length of the muscle in which they occur, the length relatively to the muscle being much greater than in the larger animals.

The average diameter of the fibers at full size is generally about 30 μ to 70 μ, which corresponds closely with the number given for man.

In the limb and trunk muscles and those ending in corium, the tendinous end, the body of the fiber and the intramuscular end may be simple or may branch. In the larger animals isolated cases of branching, intramuscular ends have been shown, while in many animals, the endings in corium for a long time have been known to branch. Hence the generally accepted idea that a muscular fiber is unbranched from end to end is untenable.

EXPLANATION OF THE PLATES.

The drawings were made from the specimens with Abbe's camera-lucida. Except when otherwise specified, Zeiss' 8 mm. apochromatic objective and compensation ocular $\times$ 4 were used, but some of the details were determined by the Zeiss' 2 mm. apochromatic, homogeneous immersion objective.

The specimens are from muscles dissociated *in situ* in nitric acid, except when otherwise stated in the description of the figures.

The intermediate part of the fiber marked *b* should be greatly elongated, 40 to 100 times, in order to give a correct idea of the form of the fiber. In the plates the comparative size of the fibers is graphically represented. In the limb and trunk muscles of the mouse, Fig. 6*t* is of the average size of a fiber. Fig. 9*b* is a small fiber, while a very large fiber is twice as large as Fig. 13*t*. In the skin of the mouse the average lies between *b* and *h*, Fig 7. That in the tongue is shown in Fig. 28*b*, in the œsophagus in Fig. 24*b*. The average in the limb and trunk muscles of the shrew is shown in Fig. 14*b*, of the bat in Fig. 4*b*, of the English sparrow in Fig. 5*h*.

PLATE VIII.

Magnification, 260 diameters.

Figs. 1 to 9.—These figures give a diagrammatic view of the form and arrangement of the fibers in the longer muscles of the mouse. Fig. 1 is of a fiber which extends from tendon to tendon. Figs. 2–8 are of tapering fibers with tendinous ends at opposite tendons and intramuscular ends at different relative distances from the tendons. Fig. 9 is of a spindle-shaped fiber with both ends intramuscular.

Fig. 1.—A typical cylindrical fiber which extends from tendon to tendon of the muscle. At the given magnification the diameter is that of many fibers found in the mouse, shrew, bat and English sparrow, while the length is that of one of the shortest fibers found in the skin of the ear of the mouse, that is $\frac{7}{10}$ mm. The ends, though different, are of types frequently found; one is tapering, the other truncate; both are made up of short finger-like processes. Nuclei are in places scattered irregularly, in places arranged in rows, and at the tendinous ends crowded together—and at *n* one shows signs of division.

Fig. 2.—A tapering fiber 7 mm. in length from a muscle 8 mm. long from the brachium of a young sparrow. Most of the intramuscular ends occurred in the middle third of the muscle, but a few fibers like this extended nearly its whole length. *t*, The tendinous end has very fine processes and is smaller than the body of the fiber, *b*. *h* Is two-thirds as large as *b* and is $1\frac{1}{2}$ mm. from the intramuscular end, *i*, which is a simple tapering end, a type common in the sparrow.

Fig. 3.—Part of a tapering fiber from the *trapezius* of a house mouse. The muscle is 20 mm. long and this end occurs near the middle. *b*, Body of the fiber; *h*, part of the fiber 1 mm. from the intramuscular end, *i*; both *h* and *i* have slight, bud-like, unstriated processes.

Fig. 4.—A tapering fiber from a muscle of the back of a gray bat. The fiber is 6 mm. long, while the muscle is 7 mm. *t*, The tendinous end has a great number of fine short processes, which give it a fringed appearance. It is larger than the body of the fiber, *b*. *h* Is $\frac{1}{2}$ mm. from the end, *i*, which has near its tip a projecting nucleus, giving the appearance of a process.

Fig. 5.—A tapering fiber 11 mm. long, from a muscle 18 mm. long, from the brachium of a young English sparrow. *t*, The tendinous end is small but rapidly expands to *b*, the body of the fiber; *h* is 3 mm. from the intramuscular end, *i*, which is a simple bifurcated form common in the English sparrow, less frequent in the other animals.

Fig. 6.—A tapering fiber from the *obliquus abdominis* of a house mouse. *t*, The tendinous end is of a type not uncommon in this and some other muscles; a number of similar ones were found *in situ*. *b*, The body of the fiber is smaller than *t*. *h* Is smaller than *b* and is 6 mm. from *i*, the bifurcated intramuscular end, a form not common in the limb and trunk muscles of the mouse.

Fig. 7.—A tapering fiber from the skin of the back of a house mouse. In the skin of the mouse this is not an unusual form of fiber, though the branches at *i* are generally shorter.

Fig. 8.—A tapering fiber from the *obliquus abdominis* of a house mouse. The branches are nearly at right angles with the intramuscular end, *i*, a condition not frequently seen in a free end. The whole fiber is small, being only about 18μ 6 mm. from the intramuscular end.

Fig. 9.—A fusiform fiber 7 mm. long from the *vastus externus*, a muscle 16 mm. long, of the house mouse. The two ends, *i i*, are both intramuscular and branched; the part *h* is 2 mm. from an end and is also branched. Dissociated in caustic potash.

Fig. 10.—Part of a tapering fiber from the *vastus externus* of a young English sparrow. The intramuscular end, *i*, is much branched, a form not common in the sparrow. The fiber has a gradual taper of 2 mm. to *b*, the body of the fiber.

Fig. 11.—The intramuscular end of a fiber from the *vastus externus* of a young English sparrow. It has a number of unstriated, bud-like processes. For 6 mm. from this point the fiber increases only slightly in diameter.

Fig. 12.—A tapering fiber from the *vastus externus* of the house mouse. *i*, The intramuscular end has many striated branches occurring from the third to the fifth tenth of a millimeter from the tip; the last $\frac{3}{10}$ mm. of the fiber is of a simple tapering form. The ends of the branches show plainly the same fringed appearance noted in the tendinous end of Fig. 4. This type of endings is frequent in the mouse and shrew. At *h*, 3 mm. from the end, the fiber is about two-thirds its full size.

PLATE IX.

Magnification, 260 diameters.

Fig. 13. A tapering fiber, 10 mm. long, from the *latissimus*, a muscle 27 mm. long, of an adult field mouse. The intramuscular end, *i*, has several branches seen both at the side and on the surface of the fiber; branches continue to be given off from the fiber until it is of full size at *b*, which is 3 mm. from *i*.

Fig. 14.—An intramuscular branched end of a fiber from the *pectoralis* of a shrew.

Fig. 15.—An intramuscular branched end of a fiber from the *pectoralis* of a shrew. Branches are given off at intervals for $\frac{4}{10}$ mm.

Fig. 16.—An intramuscular branched end from the *latissimus* of a gray bat. Branched ends are given off at intervals for $\frac{5}{10}$ mm.

Fig. 17.—An intramuscular end of a fiber from the *latissimus* of a house mouse in which the branches are long and give off secondary branches. This form of ending is rare.

Fig. 18.—An intramuscular branched end of a fiber from the *obliquus abdominis* of a house mouse. This end is rather more abrupt than those usually found. Dissociated in caustic potash.

Figs. 19–21.—Transections selected from serial sections of the *vastus externus* of a house mouse, to show the number, form and relation of the fibers in a fascicule (see Part II) at different points. *c*, Capillary. *x* Indicates the same fiber in each section. Fig. 19 is of a section about 1 mm. from the tendinous end of the muscle. It consists of six fibers, which show well the variety of shape. Fig. 20. A transection of the same fascicule at about one-fourth the length of the muscle from that shown in Fig. 19. The fascicule has increased in size by joining another, and is composed of nineteen fibers. Fig. 21. A transection of the same fascicule not far from the middle of the muscle. It has twenty-seven fibers, occupying about the same space as the nineteen of Fig. 20; most of the fibres are smaller, and some are very small. The latter are transections of tapering ends of fibers from the opposite tendon.

Fig. 22.—Transection of part of another fascicule from the same muscle at about the middle of its length. This gives an excellent idea of an appearance common in the middle of this muscle, and compared with Figs. 19–20 shows the relative diameter of fibers in the middle and near the tendon of this muscle. Figs. 19–22 are from specimens hardened in alcohol.

Fig. 23.—Part of a fiber from near the middle of the *pectoralis* of a house mouse. For three millimeters of its length it has clefts such as seen in the figure. The nuclei are arranged in rows extending from the ends of the clefts; many of them are apparently dividing, as at *n*, while some are very long. This fiber has a fine, tapering end, about 5 mm. from the part shown in the figure.

PLATE X.

Magnification of Figs. 24–31, 260 diameters, of Figs. 32–34, 180 diameters.

Figs. 24–27.—Fibers from the muscular coat of the cardiac end of the œsophagus of the house mouse. The ends are marked *t*; they are similar to those at the ends of the fibers in the tongue, but their relations were not made out. Fig. 24. A fiber 2 mm. long with both ends branched. Fig. 25. A branched end of unusual form, especially in the arrangement of the branches. Fig. 26. The body

of a fiber, bifurcated at its full size. Fig. 27. A very wide branched end.

Figs. 28 to 30.—Ends of fibers from the tongue of the house mouse, with the relative arrangement seen in the specimen. Such groups of ends found at the end of a bundle of fibers, apparently enter the corium of the mucosa.

Fig. 31.—Part of a fiber from the tongue of a house mouse, having groups of nuclei, *n*, near the end, *t*, and on the body of the fiber, *b*.

Fig. 32. A natural group of tendinous ends from the *vastus externus* of a house mouse. The form and size of the branches vary; some of them, as shown in the figures, are broken off. The branches are given off from $\frac{3}{10}$ to $\frac{7}{10}$ mm. from the tips of the fibers. On *W*, the part marked *t*, which approaches nearest to the end of *X*, is so small as to resemble an intramuscular end.

Fig. 33. The branched end of a fiber from the skin of the ear of a house mouse. This end is as great in diameter as the majority of the fibers in the ear.

Fig. 34. A fiber about 4.5 mm. long, from a penniform muscle of the antebrachium of a house mouse. It is cleft about one-third its length and the tendinous end of each portion, *t*, is branched.

FORM, ENDINGS AND RELATIONS OF STRIATED, MUSCULAR FIBERS IN THE MUSCLES OF MINUTE ANIMALS (MOUSE, SHREW, BAT AND ENGLISH SPARROW.)*

[TWO PLATES.]

SUSANNA PHELPS GAGE, PH. B.

PART II.

THE question of the form of muscular fibers is comparatively easy to solve. Their relations present a much more difficult problem.

11. ARRANGEMENT AND CONNECTION OF FIBERS.—In Sec. 1–6, Part I, and Figs. 1–9, Pl. VIII, an idea is given of the general arrangement of fibers with reference to each other in the ordinary muscles. In the study of serial sections and dissected preparations, it is seen that fibers from the opposite tendons lap to a greater or less extent, and are applied closely to each other.

In the *biceps femoris** of the mouse, a small fascicule of five fibers was traced through a large number of serial sections, when at about the middle of the muscle, three fibers of small diameter appeared and gradually increased in size, the original five gradually becoming smaller, disappeared, leaving only the three fibers which now were of full size and continued toward the opposite tendon.

* The name *vastus externus*, occuring in Part I, should be replaced by *biceps femoris* as the muscle in question seems to agree more closely with the *biceps femoris* of the rabbit than with the *vastus externus* of man. See Krause's Anatomie des Kaninchens.

Similar cases were found in other fascicules, showing clearly how fibers interdigitate (Figs. 19–22).*

Dissected preparations show similar facts which have been already mentioned, especially in Sec. 4, *a* and *b*. They also show the following special relations: Intramuscular ends were frequently found in juxtaposition to fibers of full size (Figs. 35–36), and occasionally two tapering, intramuscular ends of fibers from the same or opposite tendons were found closely connected (Figs. 37–38). The nature of the connection and whether effected by a cell cement or some other means was not determined. In many cases intramuscular ends were entirely free from other fibers, especially in the sparrow, in which few cases were found of closely adhering ends, and the question must be raised whether the above mentioned connection would not also have disappeared with further action of the reagent. At least it was found that caustic potash dissolved the connections much more completely than nitric acid.

Striated, tapering ends, which may also be called intramuscular, were found in the œsophagus of the mouse and bat, surrounded by and closely connected with unstriated fibers (Fig. 46), as previously described for the larger animals.

The methods of preparation used were not favorable to the study of the relations of tendinous ends to other parts, but in some of the polygastric muscles, the narrow raphes connecting the sections of the muscle were not dissolved, thus leaving the tendinous ends in their natural relations. They are generally irregularly truncate, and come very near together, end to end, one large end frequently being opposite a number of small ones (Fig. 47).

12. ANASTOMOSES.—Besides the connection of intramuscular ends with other fibers, mentioned in the last section, it was found that in the mouse the connection is occasionally still more intimate, true anastomoses taking place between fibers. Transitional forms between the two extremes were found. Figs. 37–44 may be considered as a series, showing the degrees of attachment between fibers; in Figs. 37–38 the fibers are simply in juxtaposition; in Fig. 39 there are fine processes on circumscribed parts, *mm*, of each fiber, which apparently dovetail together, the union between the fibers being close; in Fig. 40 the uniting branches are long and continuous, but have longitudinal clefts, as at *mm*; in Fig. 41 the clefts may be considered as much more marked, separating several small branches from each other; in Figs. 42–44 the

*Figs. 1–34 are found in Pl. VIII–X, of Part I.

anastomosis is perfect. The appearance of continuity in the succession of the striæ to one another is one of the best means found of determining the fact of anastomosis. This is only imperfectly shown in the figures.

Anastomoses were found in specimens dissociated either by caustic potash or nitric acid, from the *pectoralis, latissimus* and *biceps femoris*, taken from three house mice and a field mouse. The form of the anastomoses is various, the two fibers being sometimes connected by one branch (Fig. 44), sometimes by a number of branches (Fig. 41). The connecting branches are sometimes large (Fig. 40), sometimes small (Fig. 42), and vary in in length from 10–100 μ., and sometimes, when dissociation has not gone too far, they are seen to pass over an intermediate fiber (Fig. 43).

In some cases the anastomosis is formed by the tip of one of the fibers (Fig. 41); in others simply by a connecting branch from a tapering end (Fig. 44). In either case, if the other fiber can be traced, it is found soon to begin to taper and come to an end, generally having branches along the side. The tip of such branches generally has the fringed appearance seen in Fig. 12. Whether this is the result of a rupture or of a simple separation of fibers connected as in Fig. 39, is not known.

It does not seem unreasonable to suppose that, as branches are given off from all parts of the circumference of a fiber (Fig. 13), there may be a union more or less intimate of one fiber with several of those nearest it. In three cases it was found that one fiber anastomosed with two others (Fig. 45), and in the middle of the *biceps femoris* of one mouse, where the fibers were in their natural relation, but were particularly transparent, the appearance was of a network of anastomosing fibers.

These anastomoses were always found in that part of the muscle where tapering ends are in greatest abundance, that is, within the middle third of the muscle.

Anastomoses of striated muscular fibers have been previously found to occur in the alimentary canal of invertebrates, in the iris of birds, the ocular muscles of the sheep, and between two branches of the same fiber in a trunk muscle of the horse.

No special investigation was undertaken to determine the character of the sarcolemma or the striations or the relations of the nuclei, but many of the prepared specimens gave appearances which may be worthy of record.

13. SARCOLEMMA.—In a few cases a marked corrugation of the sarcolemma was seen (Fig. 52), and when focusing on the edge of the fiber the appearance was presented of a process extending from the bottom of each corrugation toward the sarcous substance, and joining the narrow, dark stria in the light disc of the fiber. This appearance is often seen in insect muscle.

In all the animals examined, instances were found where the sarcolemma appeared to extend as a tube beyond the sarcous substance at both the tendinous and intramuscular end of the fibers. This tubular appearance is as marked at the ends as when, in the middle of a fiber, the sarcous substance is torn and retracted, leaving the sarcolemma to bridge the interval (Fig. 44). In a few fine tapering ends from the tongue (Fig. 48), œsophagus (Fig. 46) and skin of the mouse and bat, and also in a few intramuscular ends from the trunk or limbs this appearance was seen, the striations gradually became fainter and disappeared, while the sarcous substance itself, which in the body of the fiber has a distinct color, gradually disappears, or at least loses its color, within the prolongation of the sarcolemma. In some cases, on tapering intramuscular ends or the blunt ends from the tongue and œsophagus, the sarcolemma apparently gives off filiform or sometimes nearly spherical processes in which the sarcous substance, if present at all, is not striated (Figs. 3, 11 and 27). At the tendinous end of fibers from many muscles, from all the animals examined, and prepared by nitric acid or caustic potash, especially when the end is somewhat truncate, the tubular prolongation of the sarcolemma seemed very clear, the end of the sarcous substance within it always having a delicately fringed appearance (Figs. 50–51). Tendinous ends seen *in situ*, as in the *rectus abdominis* (Fig. 47), give the same impression. In caustic potash preparations the tubular prolongation is less frequent, but a sharp line is often seen encircling the end of the fiber, as though the sarcolemma at this point had been torn, leaving the fringed sarcous substance extending a trifle beyond it. The divisions into which some tendinous ends break up (Fig. 6 and Pl. X), and the branches of intramuscular ends (Figs. 12–13), do not give the impression of being bounded by a definite membrane at their tips as at their borders, but seem to cease in an indefinite way, generally in the form of a fringe.

14. NUCLEI.—In general the nuclei are more numerous in proportion to the volume of the fiber at both the tendinous and

intramuscular ends (Figs. 1 and 4) than in the body of the fiber. They frequently are irregularly placed, but sometimes form distinct rows (Figs. 1 and 23). In the latter case many of the nuclei are elongated, and some show signs of division. Nuclei also occur in clusters (Fig. 31) resembling the end-plates figured by Krause, but in the tongue and œsophagus of bat and mouse fibers were found on which several such clusters occur, while Krause thinks there is only one end-plate to each fiber. A nucleus was always found near the tip of an intramuscular end, and generally one at the angle where a branch is given off. In caustic potash preparations the nuclei are much more distinct than in nitric acid preparations, unless the latter are stained. (See methods.)

15. STRIATIONS.—At the tapering end of a fiber the striations generally become less marked, and beyond the last nucleus they are sometimes clear (Figs. 2 and 14), sometimes indistinct (Fig. 4), and sometimes there is simply a granular appearance (Figs. 7 and 11). When the tendinous ends break up into processes the striation becomes less marked, and in the fine fringed processes of tendinous ends and intramuscular branches (Sec. 13) ceases altogether.

16. FASCICULES.—In studying serial sections of a portion of the *biceps femoris* of the mouse it was found that the fascicles, though changing greatly in shape as seen in Figs. 53–55, continued from tendon to tendon as usually described; but both the secondary fascicles, as shown by the fine lines in the same figures, and the tertiary fascicles, or *fascicules*, as shown in Figs. 56–69, are neither constant in shape, nor in position in the fascicle, nor do they extend in their integrity from tendon to tendon. In tracing from section to section it is seen that a fascicule becomes divided by septa into two or more; these may be permanent or may disappear and others appear, and that two fascicules at first separate may unite. The figures show these changes more clearly than can a description, while the gradual transition between two forms can be only seen by close study of the sections themselves. The fibers composing one of these fascicules are shown in Figs. 19–21.

This subject of fascicules has not been investigated as fully as is desirable; its special importance seems to be in connection with the determination of some of the relations of fibers to each other, which can only be finally settled by examining serial sections.

17. METHODS.—All important or doubtful points in connection with this investigation were tested by at least two methods:

a. Fresh muscle was dissected with needles in blood serum only for the purpose of measuring the diameter of fibers.

b. Dissociation in nitric acid. In order to get good results it was found necessary to put the specimen into the reagent directly after death and the removal of the skin. A twenty per cent. solution of nitric acid (conc. nitric acid 20 cc., water 80 cc.) softens the connective tissue, the time necessary varying with the temperature, being 24 h. if below 18° C., and 1 h. if 40–50° C. Above 40° C. frequent examination is necessary to avoid too great disintegration. The acid is removed by placing the specimen in water for one-half to 24 h. A few fascicles of a muscle are placed on a slide, in glycerine containing picric acid or picro-carmine which gives a general stain, and gently dissected with coarse needles: the excess of glycerine is removed; a drop of warm glycerine jelly is allowed to spread slowly over the preparation; the fibers are arranged with the needles so as to lie as straight as possible; the slide is cooled until the jelly has a glutinous consistency and then is covered by a warm cover or one thinly coated with warm glycerine jelly. In this way the fibers retain their places on the slide.

If the specimen was put into the acid *in toto*, so that the muscles were held naturally extended, only a slight shrinkage took place in their length, but if a detached muscle was put into the acid a shrinkage of one-third its length was observed. In both cases the dissected fibers were somewhat longer than the shrunken muscle from which they were taken, probably owing to the fact that the connective tissue shrinks more than the fibers, and draws the ends of the muscle together.

It was found possible to stain the nuclei after dissociation in the acid if, after thoroughly removing the acid by water, the muscle was placed 12 h. in Koch's dilute, red, tubercle stain. After staining, a few fascicles are placed on a slide with 20 per cent. alcohol and a drop of picric acid to give a general stain; this was replaced by 50 per cent. alcohol and then by 95 per cent. In the last the fibers, which in the 20 per cent. alcohol are stiffened, again are flexible and easily dissected by needles. Clove-oil collodion is then placed on the specimen and partially dried to hold the fibers in position, and it is then mounted in Canada balsam. Though this stain is excellent at first, it was found that after two months some of the specimens were much faded.

Prof. Gage has recently found that by placing muscles after being freed from nitric acid by soaking in water, in a saturated aqueous solution of alum, the fibers, for some weeks at least, can be dissected as well as when first prepared. The nuclei stain well in hæmatoxylin.

c. Dissociation in caustic potash. A muscle or limb is placed as fresh as possible into 35–40 per cent. solution of caustic potash (caustic potash 35 or 40 grams, water 65 or 60 cc.) for 15–30 min., depending upon the amount of connective tissue present, when a few fascicles are removed to a slide, dissected quickly with needles and immediately covered by potassium acetate (40 grams potassium acetate to 25 cc. of water), and mounted permanently in potassium acetate or glycerine jelly. In dissociating muscles in this way, a shrinkage of at least one fourth in length occurs.

d. For serial sections, the animal was injected from the heart with fine red mass, and the muscles prepared in the usual way for serial sections in paraffine.

SUMMARY OF PART II.

In the longer muscles, which are composed chiefly of tapering fibers, those from opposite tendons interdigitate or lap by each other for some distance, and the tapering ends are applied to fibers of full size, or more rarely to tapering ends, from the same or the opposite tendon.

Anastomoses of various forms occasionally occurred near the middle of several limb muscles of the mouse, between two fibers. Previously such anastomoses, occurring in limb or trunk muscles, have only been described in the ocular muscles of the sheep.

The sarcolemma, in some cases at least, sends processes to the dark line (Krause's) in the light disc, as in insect muscle, and on many fibers it appears to be a tubular sheath extending beyond the sarcous substance proper, at both the tendinous and intramuscular end. The sarcous substance ends within this tube by minute unstriated processes.

The nuclei are irregularly placed on the fiber, or occur in rows or groups, but there is always one near the tip of an intramuscular end, and usually one near the point where a branch is given off.

GENERAL CONCLUSIONS.

In general form and arrangement the muscular fibers of these minute animals agree with those of man and the larger vertebrates.

On finding spindle-form elements in the striated muscles of the trunk, Biesiadecki and Herzig drew the conclusion that in form and relations striated muscular fibers of the trunk show resemblance to the unstriated fibers. In comparing the facts presented in this paper concerning the branched endings and intimate relations of the fibers of skeletal muscles, with the known form and relations of

the muscular fibers in the heart of adult and fœtal vertebrates (see Weismann and Gage), it is seen that the differences between skeletal and cardiac muscle are not so radical as usually supposed.

The fact that anastomoses occur between fibers points to the conclusion that the physiological connection may also be as intimate as the morphological, and gives rise to the query whether each of the fibers so united has a separate connection with a nerve.

EXPLANATION OF THE PLATES.

PLATE XI.

Magnification of Figs. 35–44, 260 diameters; of Fig. 45, about 50 diameters.

Fig. 35.—A tapering intramuscular end *i*, closely adherent to the surface of a fiber of full size. From the brachium of a young English sparrow.

Fig. 36.—A tapering and branched intramuscular end *i*, closely attached to the side of a fiber at its full size. From the shoulder of a house mouse.

37.—Two tapering and branched intramuscular ends, belonging to fibers extending in the same direction, adherent to each other, one terminating .2 mm. from the tip of the other. From the *biceps femoris* of a house mouse.

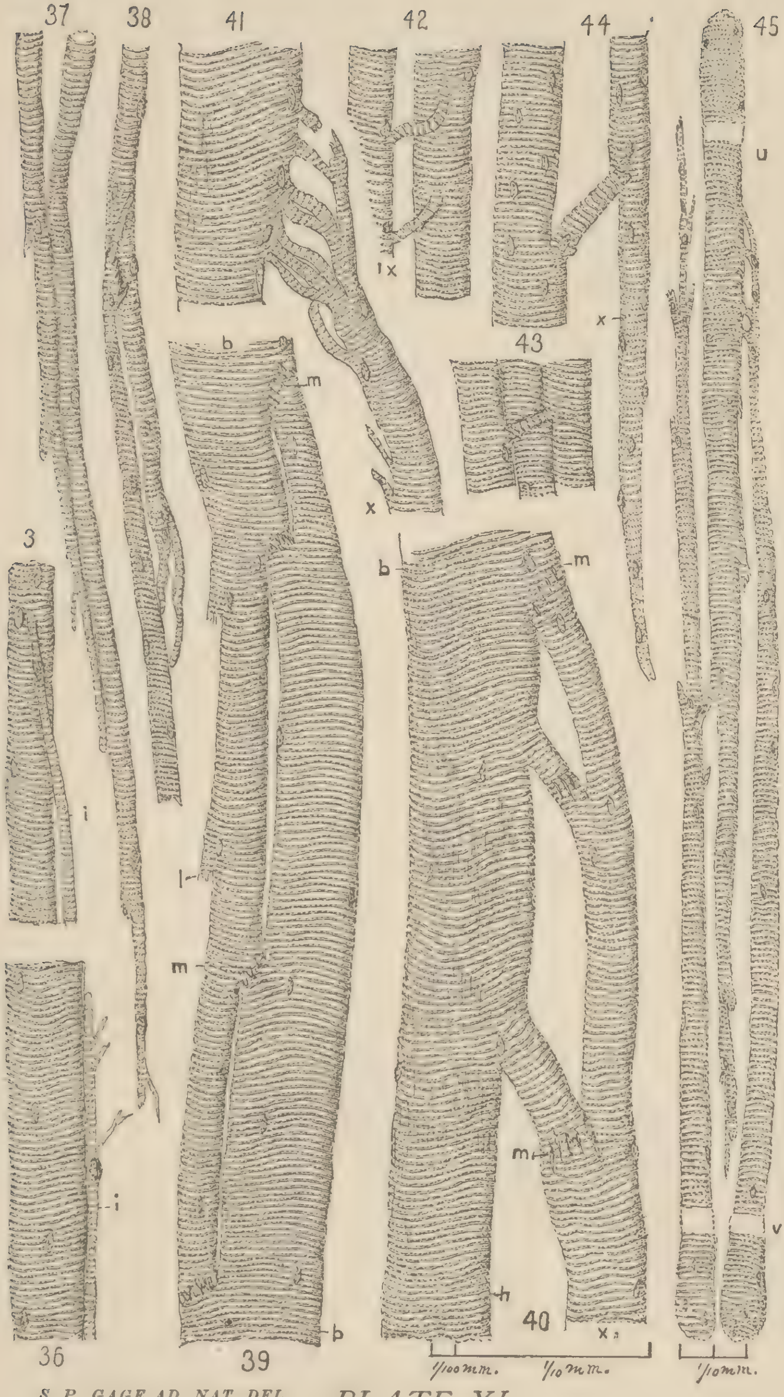
Fig. 38.—Two tapering and branched intramuscular ends, belonging to fibers extending from opposite tendons, adherent to each other and lapping for about .2 mm. From the *pectoralis* of a house mouse.

Fig. 39.—The thick tapering ends of two fibers from opposite tendons. They are closely connected at *mm*. The line of union is zigzag, as though the fine processes such as seen at *l* interdigitate. At *bb* the fibers are of full size. From near the middle of the *biceps femoris* of a house mouse.

Fig. 40.—An anastomosis of two fibers, in the connecting branches of which are seen a number of longitudinal clefts. The smaller fiber *x* comes to an end at this point, and in the specimen can be traced for some distance toward the tendon. The larger fiber has its maximum size at *b*, and from *b* it can be traced 4 mm. to its tapering, branched, intramuscular end, one of the branches forming an anastomosis with another fiber. From the *biceps femoris* of a house mouse.

Fig. 41.—An anastomosis of two fibers by a number of branches from the tip of one of them. The smaller fiber *x* in the

For general considerations, see Pl. VIII-X.



S. P. GAGE AD. NAT. DEL.

PLATE XI.

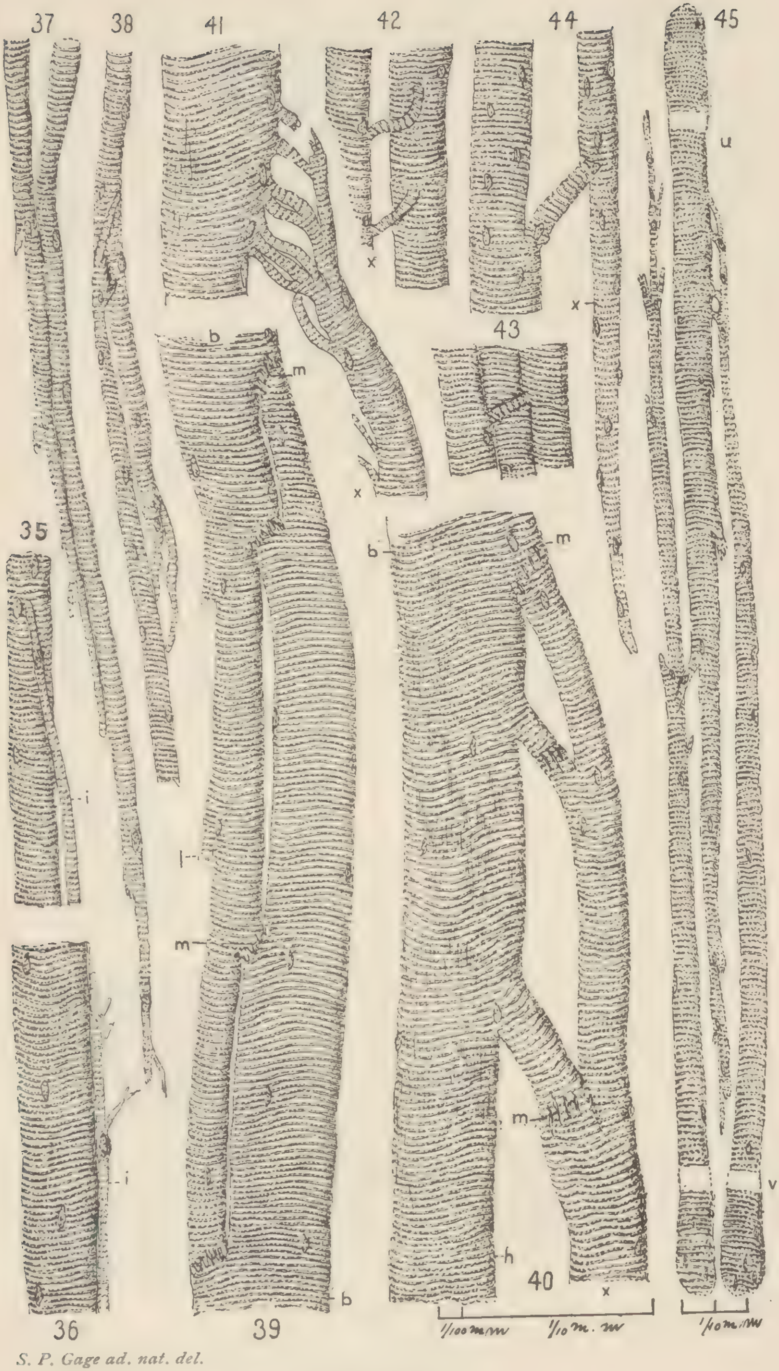


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PLATE XI.

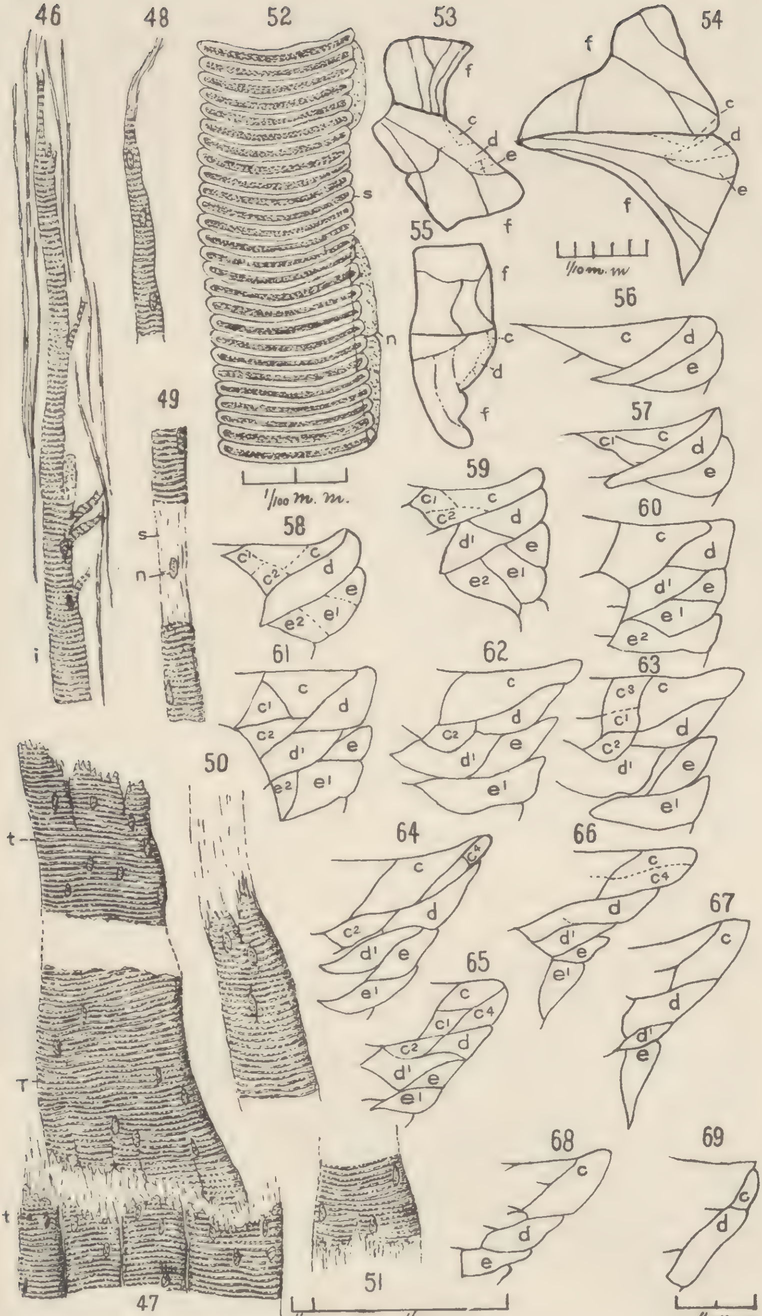

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PLATE XII.

specimen has branches at intervals for 1 mm., where it becomes of full size. From the *biceps femoris* of a house mouse.

Fig. 42. An anastomosis of two fibers, the connecting branches being seen at the side of one fiber, on the surface of the other. In the specimen the smaller fiber *x* continues to branch and about 1 mm. from this point ends in a fine point. From the *biceps femoris* of a house mouse.

Fig. 43.—An anastomosis of two fibers in which the connecting branch passes over a third fiber. From the *biceps femoris* of a house mouse.

Fig. 44.—An anastomosis in which the smaller of the connected fibers *x* is seen to have a tapering end. From the *biceps femoris* of a house mouse, dissociated in caustic potash.

Fig. 45. The anastomoses of one tapering fiber with two others from the opposite tendon, showing in a typical way the relations of anastomosing intramuscular ends to each other. The portion from *u* to *v* represents 3 mm., while the whole muscle is 17 mm. long. The intramuscular ends are branched and two of them, after anastomosing, end freely. From the *biceps femoris* of a house mouse.

PLATE XII.

Magnification of Figs. 46–51, 260 diameters; Fig. 52, 660 diameters; Figs. 53–55, 25 diameters; Figs. 56–69, 45 diameters.

Fig. 46.—The tapering end *i* of a striated fiber from the cardiac end of the œsophagus of a gray bat. It is branched and is seen *in situ*, surrounded by unstriated fibers.

Fig. 47—Tendinous ends of the *rectus abdominis*, a polygastric muscle, from a house mouse. *T* and *t*, ends of a fiber 5 mm. long. *t'*, ends of much smaller fibers, seen in their natural relations opposite to *T* on the other side of the narrow tendinous raphe.

Fig. 48.—A tapering end from the tongue of a mouse, with a tubular prolongation of the sarcolemma apparently extending beyond the sarcous substance.

Fig. 49.—A portion of a fiber from the *latissimus* of a shrew, in which the sarcous substance has separated, the tubular sarcolemma bridging the interval. *n*, a nucleus on the sarcolemma.

Figs. 50 and 51. Tendinous ends, from which extends a transparent sheath, apparently a prolongation of the sarcolemma beyond the sarcous substance, which terminates in fine fringed processes showing no sign of striation. From a short muscle of the back of a house mouse.

Fig. 52. Part of a fiber showing a wavy contour. The bottoms of the depressions apparently join the dark striæ (Krause's lines) in the middle of the light discs. The nuclei *nn* are outside the sarcolemma, and one is dividing. From a long muscle of the inside of the leg of a gray bat. Drawn with a 2 mm. Zeiss, apochromatic, homogeneous immersion objective and ocular x4, in optical section a little below the middle of the fiber.

Figs. 53–55.—Transections selected from a series into which a small portion, consisting of two fascicles, *f*, *f*, of the *biceps femoris* of the house mouse was cut. Fig. 53 is at a point $1\frac{1}{2}$ mm. from a tendon. Fig. 54 is $3\frac{1}{2}$ mm. from the tendon. Fig. 55 is 13 mm. from the first tendon and 1 mm. from the other. The same two fascicles are seen in each figure, but differ in form and relative size. The fine lines indicate the secondary fascicles into which they are divided, and these are not constant in form, number or relative position. The dotted lines enclose a few tertiary fascicles or fascicules, *c*, *d*, *e*, of which more and enlarged sections are seen in the following figures.

Figs. 56–69. Fourteen transections selected from the same series as Figs. 53–55, showing the same fascicules *c*, *d* and *e*, Fig. 56 corresponding to Fig. 54, Fig. 68 to Fig. 55. These consecutive figures are from points in the muscle varying from .2 to 2 mm. apart, and intermediate and transitional forms occur between them. Fig. 56. Three distinct fascicules, which, up to this point in the muscle ($3\frac{1}{2}$ mm. from the tendon) have each been formed by the union of two or more fascicules as distinct as these. Fig. 57.—The fascicule *c* has become divided into *c* and c^1 by a septum. Fig. 58.—Two new septa appear in *c* and two in *e*, giving *e*, e^1, e^2. Fig. 59.—A septum appears in *d*, giving *d* and d^1. Fig. 60.—The septa in *c* disappear, and also the one between e^2 and a neighboring fascicule. Fig. 61.—*c* is again divided by septa, in a somewhat different manner from the first division, into *c*, c^1, c^2, and e^2 is again separate from its neighbor. Fig. 62.—*c* and c^1 unite, and also e^1 and e^2. Fig. 63.—*c* is again divided into *c*, c^1 c^3, and d^1 unites with a fascicule at the left. Fig. 64.—*c* is divided anew, in another part, into *c* and c^4 and d^1 separates from its neighbor. Fig. 65.—*c* again divides into *c* and e^1. Fig. 66.—c^1 and c^1 unite, and also *d* and c^2. From this point the fibers diminish in number, and the fascicules unite and disappear. Fig. 67.—c^1 and c^4 unite and *e* and e^1. Fig. 68.—d^1 disappears. Fig. 69.—*e* disappears. The remainder of the sections to the tendon were not perfect enough to trace the

fascicules farther. Fig. 19 is an enlarged view of *e*, Fig. 53, showing the fibers; Fig. 20 is of Fig. 54, *e*, and Fig. 56, *e*; Fig. 21 is of Fig. 57, *e*.

Fig. 55–69 drawn with one-half and three-fourths inch Bausch & Lomb objectives.

BIBLIOGRAPHY.

Brief statements are given of the special points in the articles bearing upon the present paper, and the section of this paper to which they refer is given in parenthesis.

1. *Baur, A.*—Der Bau der Chitinsehne am Kiefer der Flusskrebse und ihr Verhalten beim Schalenwechsel. Arch. für Anat. u Phys., 1860, pp. 113–144, 2 pl. The figures show the sarcolemma extending beyond the sarcous substance into the chitin. (See Sec. 13.)

2. *Beale, L. S.* Distribution of nerves to the elementary fibers of striped muscle. Phil. Tr., London, 1860, pp. 611–619, 1 pl. Gives figures of the capillaries and nerves in the diaphragm of a white mouse, and says that most of the nuclei seen on the sarcolemma belong to blood vessels and nerves. p. 614. (Sec. 14).

3. ——— On the structure and formation of the sarcolemma of striped muscle, and the exact relation of the nerves, vessels and air-tubes (in the case of insects) to the contractile tissue of muscle. Trans. Royal Micr. Soc., 1864, pp. 94–108, 2 pl. Says sarcolemma has not been demonstrated in the eye-lids and eye-balls of the green tree-frog, nor in the heart or tongue, that is, where the fibers branch or are finely divided, nor in developing fibers. p. 95. (Sec. 13). There are fine processes connecting the sarcolemma at every point with intermuscular connective tissue, p. 100. (Sec. 11, 13).

4. ——— New observations upon the minute anatomy of the papillæ of the frog's tongue. Quart. J. Micr. Sc., 1869, pp. 1–18, 4 pl. Says the branches ($\frac{1}{2}$ ″ in width) (Sec. 5) of muscular fibers end at the summit of the papillæ, there being no striation beyond the nucleus which is near the end of each branch, the striated substance following the nucleus and being formed by it. pp. 13–14. (Secs. 5, 6, 15, 14).

5. *Biesiadecki, A., u. Herzig, A.*—Die verschiedenen Formen der quergestreiften Muskelfasern. Sitzungsb. d. k. Akad. d. Wissench. Math-naturw. Cl., Wien, 1858, pp. 146–149, 3 pl. Figure cylindrical, tapering and fusiform fibers, and both tapering and branched ends from the trunk muscles of some of the larger

animals (Sec. 1, 2, 3, 7); a dichotomously divided end from a trunk muscle of the horse, the two branches of which anastomose (Sec. 12); and fibers from the frog's tongue, both ends of which are large and branched (Sec. 6); and draw the analogy on account of form between smooth and striped muscle, p. 149. (See conclusions).

6. *Bremer, L.*—Ueber die Muskelspindeln nebst Bemerkungen über Structur, Neubildung und Innervation der quergestreiften Muskelfaser. Arch. f. mikr. Anat. Bd. XXII, 1883, pp. 318–356, 2 pl. Says that in the mouse chains of nuclei are found in the spring, which develop into new muscular fibers. p. 352. (See 14).

7. *Bowman, W.*—On the minute structure and movements of voluntary muscle. Phil. Tr., Lond., 1840. pp. 457-501, 4 pl. Shows the sarcolemma of insect muscle as corrugated, with processes extending from the depressions to the sarcous substance. (Sec. 15).

8. *Busk and Huxley.* Manual of human histology. 2 vol., illustrated. London, 1853. A translation of Kölliker's histology. Figure of a branched ending in the lip of a rat, the ends of the branches being unstriated and mingling with the fibers of the corium, p. 245, vol. I. (Sec. 8, 15).

9. *Dogiel, J.*—Ueber den Musculus dilator pupillæ bei Säugethieren, Menschen und Vögeln. Arch. f. mikr. Anat., Bd. VI, 1870, pp. 89–99, 1 pl., and Neue Untersuchungen über den pupillenerweiternden Muskel der Säugethiere und Vögel. Arch. f. mikr. Anat. Bd. XXVII, 1886, p. 403, 1 pl. Figures branches and anastomoses of striated fibers in the iris of birds. (Sec. 12).

10. *Felix, W.*—Die Länge der Muskelfaser bei dem Menschen und einigen Säugethieren. Leipzig, 1887. pp. 1–9, 1 Fig. From the Festschrift für Albert von Kölliker. Finds length of fibers in man 53 to 123 mm., in other large animals 20 to 80 mm. (Sec. 4); in man and the rabbit fibers branch, and in man anastomose, p. 6–9, (Sec. 7, 12); gives a method of preparing muscles, separated from the skeleton, without shrinkage, p. 5. (Sec. 17).

11. *Fick, A.*—Ueber die Anheftung der Muskelfasern an die Sehnen. Arch. für Anat. u. Phys., 1856, pp. 425–432, 1 pl. Shows the sarcolemma extending into the tendon. (Sec. 13).

12. *Gage, S. H.*—Muscular tissue. Reference hand-book of medical sciences, Vol. V, pp. 59–74, illustrated. New York, 1887. Describes in the mouse striated fibers extending on the œsophagus to the stomach, p. 59, (Sec. 6); tapering intramuscular ends in the

mouse, and branched ends in the cat, p. 62. (Sec. 7); states that intramuscular endings are always applied to fibers of full size, p. 92, (Sec. 11); calls attention to the necessity of measuring fibers at their full size, p. 63, (Sec. 5); figures cardiac muscle from the great groups of vertebrates, pp. 66–71; thinks a stimulus might be transmitted from one lapping fiber to another, p. 72. (See conclusions).

13. *Haller.*—Elementa physiologiæ. 1757-1766. Says some fibers have fine, acute ends, Vol. IV, Sec. 1, p. 3; hence Krause gives him the credit of discovering intramuscular ends.

14. *Haycraft, J. B.*—Upon the cause of striation of voluntary muscular tissue. Quart. J. Micr. Sc. 1881, pp. 307–329, illustrated Thinks the fiber is structureless, the cross-markings being due to its beaded form, with perhaps the exception of Dobie's (Krause's) line, which occurs at the narrow part (Sec. 13), and shows the different appearances due to change of focus of the microscope, pp. 315, 327. (See Fig. 52).

15. *Heitzmann, C.*—Microscopical morphology of the animal body, pp. 849. Illustrated. New York, 1883. Says the sarcolemma is a structureless, corrugated membrane, without nuclei, passing around the end of the muscular fiber, which is joined to the tendon by connective tissue, p 267. (Sec. 13.)

16. *Herzig, A.*—Ueber spindelförmige Elemente quergestreifter Muskelfasern. Sitzungsb. d. k. Akad. d. Wissench. Math-naturw. Cl. Wien, Bd. XXX, 1858, pp. 73–74. First found spindle-form fibers in muscles of the cow and sheep. (Sec. 3.)

17. *Jousset et Bellesme.*—Sur les anastomoses des fibres musculaires striées chez les invertébrés. Compt.-rend. Acad. d. Sc. Par. T. XCV, 1882, p. 1003–4. Find fibers anastomose in the digestive tube of larval insects and the gastric appendages of crustacea, where they tend to produce simultaneous movement. (Sec. 12 and conclusions.)

18. *Kölliker, A.*—Handbuch der Gewebelehre des Menschen, pp. 749. Illustrated. Leipzig, 1867. In the middle of the longer muscles the fibers are spindle-form, and at the ends are tapering, p. 159. (Secs. 1–3 and 11.) Thinks fully formed fibers may divide into two or more by longitudinal clefts, p. 178. (Sec. 10.) In developing muscle, nuclei occur in rows and groups, p. 176. (Sec. 14.)

19. *Krause, W.*—Die motorischen Endplatten der quergestreiften Muskelfasern. Hannover, 1869. pp. 192. Illustrated. A

collection of papers, mostly from periodicals. Says that fibers, apparently longer than 40 mm., are really composed of two spindle-form elements, p. 4. In short muscles and in the longest muscles of small animals, the fibers are as long as the muscle, p. 5. (Sec. 1–4.) A fiber has only one end-plate, p. 79, and end-plates are easy to examine in the diaphragm of the mouse, p. 88. (Sec. 14.) The sarcolemma extends around the fine pointed end of fibers, p. 4. (Sec. 13.)

20. *Lawdowski.* — Militärärzlichen Jour., 1884 and 1885, Abstract in Jahresb. ü. d. Fortschr. d. Anat. u. Physiol., 1885, p. 496. Says in rat and mouse the fibrillæ go over directly into tendon. (Sec. 13.)

21. *Margo, T.*—Neue Untersuchungen über die Entwickelung, das Wachsthum, die Neubildung und den feineren Bau der Muskelfasern; Wien, 1861. pp. 74, 5 pl., from Sitzungsb. d. k. Akad. d. Wissench, Math-naturw. Cl. Wien. Bd. XX. Shows a branched ending from the intestine of an insect (Sec. 8). and makes the generalization that branches and anastomoses result from the incomplete joining of the sarcoplasts or elements from which the fibers arise, p. 37. (Secs. 7, 8 and 12.)

22. *Milne-Edwards.*—Leçons sur la physiologie et l' anatomie comparée de l' homme et des animaux. Paris, 1857–1879. T. X, pp. 447 and 451, Bibliography of Muscle.

23. *Pearson, L.*—The muscular coats of the œsophagus of the domesticated animals. Unpublished thesis. Shows the arrangement of the fibers in bundles which interdigitate and cross on the ventral and dorsal side (Sec. 6), and also tapering fibers with pointed, blunt or branched ends. (Sec. 7, 8.)

24. *Powwyssozki, W.*—Ueber die Beziehungen der quergestreiften Muskeln zum Papillärkörper der Lippenhaut. Arch. für mikr. Anat., Bd. XXX, 1887, pp. 327–335, 1 pl. Shows branched endings, each branch being formed by a fibril, which gradually merges into a tendon attaching to the basal membrane of the *stratum mucosum.* (Sec. 8, 13.)

25. *Ranvier, L.*—Leçons, d' Anatomie générale sur le système musculaire. Paris, 1880. The striated muscular fibers of the lymph-hearts of the frog branch, p. 336. (Sec. 7.)

26. *Rollett, A.*—Sitzungsb. d. k. Akad. d. Wissench. Math-naturw. Cl. Wien. Bd. XXXI, 1856, heft i und ii, pp. 176–180, 1 pl. Found tapering intramuscular ends in the cow, calf, frog, carp, rabbit and man (Sec. 7), but as far as traced, these tapering

fibers remained small; hence concludes that they are developing fibers which have not yet reached from tendon to tendon, p. 179. (Sec. 5.)

27. *Rouget, C.*—Terminaison des nerfs moteurs dans les muscles chez les reptiles, les oiseaux et les mammifèrs. J. de la physiol. de l' homme, Par. T. V, 1862, pp. 574–593, 2 pl. Represents the outline of fibers by a wavy line, in reptiles, birds, rabbit, cat and man. (Sec. 13.)

28. *Tergast, P.*—Ueber das Verhaltniss von Nerven und Muskel, Arch. für mikr. Anat. Bd. IX, 1873, pp. 36–46, 1 pl. Figures striated branches and anastomoses of fibers in the ocular muscles of the sheep, which closely resemble the drawings of mouse muscle accompanying this article. (Sec. 7, 12.)

29. *Thanhoffer, L. v.*—Beiträge zur Histologie und Nervenendigung der quergestreiften Muskelfasern. Arch. für mikr. Anat. Bd. XXI, 1882, pp. 26–44, 2 pl. Says sarcolemma has two layers, the outer with few nuclei unites with the tendon, the inner has many nuclei and contains Krause's lines; the numerous nuclei at the end of a fiber are simply indications of lymph spaces, p. 42. (Sec. 13, 14).

30. *Thin, G.*—A contribution to the anatomy of connective tissue, nerve and muscle, with special reference to their connection with the lymphatic system. Proc. Roy. Soc., Lond., 1874, pp. 515–531, 3 pl. Figures lymphatics of mouse muscle, and thinks the nuclei of the sarcolemma belong to the lymphatic system. (Sec. 14).

31. *Verson, E.*—Zur Insertionweise der Muskelfasern. Sitzungsb. d. k. Akad. d. Wissench., Math-naturw, Cl., Wien, Bd. LVII, 1868, pp. 63–66, 1 pl. Shows sarcolemma going over into tendon. (Sec. 13).

32. *Weber, E. H.*—Funke's Lehrbuch der Physiologie, Bd. I, 1858, p. 649. Says muscle fibers may be pointed, rounded or divided at both ends. (Sec. 7, 8).

33. *Weismann, A.*—Musculatur des Herzens. Arch. f. Anat. Physiol. u. wissench. Med., 1861, pp. 41–63. 3 pl. Believes difference in form of fibers does not affect the function nor quickness of action, in the heart the form being that which gives greatest strength; gives a series of figures showing heart muscle in different animals and in different stages of development. (See Conclusions).

34. ——— Zur Histologie der Muskeln. Ztschr. f. rat. Med. Bd. XXIII, 1865, pp. 26–45. Says he first used caustic potash to demonstrate the sarcolemma around the tendinous end of a fiber. (Sec. 13).

35. *Winkler, F. N.*—Beiträge zur Kentniss der Herzmusculatur. Arch. f. Anat. u. Physiol., 1865, pp. 261-300, 2 pl. Shows anastomoses of muscular fibers in the heart.

Nearly all of these articles contain more or less complete bibliographies of the form and structure of muscular tissue, those in Krause, Kölliker and Milne-Edwards being especially good.